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# Vaccine Distribution Strategies against Polio: An Analysis of Turkey Scenario

## Abstract

As a result of the ongoing Syrian civil war, almost 3 million refugees moved to Turkey since 2011 because of security reasons. However, the government operated refugee camps have been largely inadequate to accommodate this huge number of refugees. Therefore, almost 91% of the Syrian refugees live out of government-operated camps. According to a Turkish Disaster and Emergency Management Agency (AFAD) report, 45.4% of the children under 5 years old who live out of camps are not vaccinated against polio. This presents a serious health threat to the local population and the whole region. In order to deal with this potential risk, local vaccine distribution strategies that encourage vaccination should be developed for the cities that are close to Syrian border. We develop a mathematical model with which we determine the optimal number of polio vaccines that needs to be administered for each age group and the region considering the vaccination history of individuals. Different vaccination strategies (i) by age, (ii) by region, and (iii) by age-population are compared for cost effectiveness.

## Keywords

Vaccine distribution, polio, mixed integer programming

## Disciplines

International Public Health | Operational Research

## Comments

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# **Vaccine Distribution Strategies against Polio: An Analysis of Turkey Scenario**

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## **Abstract**

As a result of the ongoing Syrian civil war, almost 3 million refugees moved to Turkey since 2011 because of security reasons. However, the government operated refugee camps have been largely inadequate to accommodate this huge number of refugees. Therefore, almost 91% of the Syrian refugees live out of government-operated camps. According to a Turkish Disaster and Emergency Management Agency (AFAD) report, 45.4% of the children under 5 years old who live out of camps are not vaccinated against polio. This presents a serious health threat to the local population and the whole region. In order to deal with this potential risk, local vaccine distribution strategies that encourage vaccination should be developed for the cities that are close to Syrian border. We develop a mathematical model with which we determine the optimal number of polio vaccines that needs to be administered for each age group and the region considering the vaccination history of individuals. Different vaccination strategies (i) by age, (ii) by region, and (iii) by age-population are compared for cost effectiveness.

## **Keywords**

Vaccine distribution, polio, mixed integer programming

## **1. Introduction**

As a result of increasingly worsening humanitarian conditions in Syria due to the civil war, the number of refugees in Turkey reached almost 3 million. Turkish government set up 21 government operated camps to host the refugees. However, the total capacity of those camps is not enough to accommodate the massive number of refugees. Consequently, there are many unregistered Syrian who are in border provinces of Turkey, including Hatay, Sanliurfa, Gaziantep, and Adana. Disaster and Emergency Management Agency in Turkey (AFAD) reports that almost 91% of the refugees live out of the camps. The fact that majority of the refugees are not accommodated in the camps presents health risks for the population living in the region because of the difficulties in medical screening of refugees and related record keeping [1]. Due to war conditions in Syria, the routine immunization activities are interrupted, and most refugees do not have medical records. Moreover, worsening humanitarian conditions increase the spread of infectious diseases such as polio, measles, and chicken pox. According to an AFAD report, only 45% of the children are vaccinated against polio and measles, and this ratio dramatically decreases to 25% for those children who live out of camps. Having national borders with countries that have low population immunization and the large sudden refugee movements substantially elevated the risk of spread of the infectious diseases within Turkey. Attesting to this, diseases that have been eradicated started to appear in Turkey. For example, in 2002, Turkey has received a certificate from World Health Organization for successful eradication of the wild polio virus and ensuring a poliomyelitis free region [2]. However, due to the occurrence of three polio cases in Turkey and Syria in 2015 [3] and movements of a large number of Syrian refugees are threats to sudden polio outbreaks. In order to fully immunize the population against such sudden outbreaks, vaccination is an effective strategy [4].

The problem is to allocate and distribute the optimal number of polio vaccines throughout Turkey in order to mitigate the risk of an outbreak. In the literature, although not specific for the polio case, there are studies on the vaccine distribution and allocation problem for infectious diseases. Jacobson et al. [5] consider the problem of quantity decision for vaccine procurement for a set of childhood diseases. They propose an integer linear programming model to minimize the cost of vaccine administration based on vaccine types and set of available vaccine combinations. Smalley et al. [6] consider the problem of optimal allocation of vaccine distribution strategies to decrease the cholera cases in Bangladesh. Their mixed-integer programming model answers where, when, and in what quantity vaccines are needed to minimize the disease incidences. What-if analysis are performed to evaluate cost comparison of age, region and age-region strategies. Duijzer et al. [7] review the vaccine supply chain studies by classifying them in terms of product (vaccine type), production (the required dose to provide protection against disease), allocation and distribution of vaccines (e.g., inventory control, facility location selection, and supply logistics of a perishable product). They analyze extant studies for existing and sudden outbreaks in developing countries. The study concludes that there is a need for operation research/operation management community to develop and analyze scheduling problems for the vaccination policies for children. There are also studies that focus on the vaccine supply chain performance in terms of vaccine availability, cost effectiveness, protected population, morality, and impact of redesigning the radical distance chains to eliminate storage locations [8-10].

The objective of this study is to develop a mathematical model to determine the optimal number of polio vaccines to be administered to individuals who live in highly populated refugee-dense regions. The proposed mathematical model maximizes the percentage of protected population against polio under different budget constraints. We analyze the cost effectiveness of the age-, region-, and age-population-based distribution strategies to assist the healthcare decision makers. The problem is unique and timely as it is inspired by a real health threat for children. Our work supports the development of a solution strategy to eradicate the polio virus from the region given the complexities of the refugee problem.

## 2. Problem statement

We propose a mixed integer linear programming model by which optimal vaccine quantities for multiple regions and age groups are determined to maximize the number of vaccinated population against polio. We apply this model to five cities that have the highest refugee population. Each of these five cities are categorized into two groups, namely high risk and low risk groups with regards to the age of the population. High risk group includes children who are under 6 years old (0-59 month), and the low risk group contains the individuals aged between 10 and 12. Like many studies in the medical literature [7], we consider vaccine allocation strategies over age groups and pay the highest attention to children due to their vulnerability for infectious diseases. The four cities out of five have the government operated refugee camps. Since it is comparatively easier to perform medical screening and to administer the missed vaccine doses, the ratio of the vaccinated population against polio in the camps are lower, 25% vs 45% [1]. Moreover the dose and the type of the polio vaccine (OPV- live attenuated oral polio vaccine, IPV-inactivated polio vaccine) differ with respect to age of the individual and whether the individual is previously vaccinated. Thus, the cost of vaccination depends on the age and the vaccination history of the individuals. Table 1 lists the vaccine types that need to be administered and vaccination costs for various age and vaccination histories. Two doses OPV need to be administered to the local population who are under 6 years old, and the time between administration of doses must be at least one month [11]. Children, who are under 6 years old and haven't been vaccinated before, need to have three doses of IPV. The time interval between the 1<sup>st</sup> dose and the 2<sup>nd</sup> dose must be at least 2 months, and the 3<sup>rd</sup> dose must be administered 8 months after the 2<sup>nd</sup> dose. Only one dose of IPV needs to be administered to the children of ages 10 to 12 years old, who had previous vaccine doses [11]. Three doses of OPV need to be administered to 10 to 12 year old children, who have not been vaccinated before. There must be one month between 1<sup>st</sup> and the 2<sup>nd</sup> dose. The 3<sup>rd</sup> dose must be administered 8 months after the 2<sup>nd</sup> dose. We assume that each vaccinated individual receives the required doses in the same year. Vaccination cost includes the cost of vaccine, cost of freight (0.25 US\$ [6]) and cost of delivery (0.3 US\$ [6]) times the required number of doses. OPV costs comparatively less than IPV, 0.15 US\$ versus 1.00 US\$ [4]. Table 2 presents the population of five cities where the refugees are located along with age and type of accommodation information (i.e., inside-camps vs. outside-camps).

Table 1: Vaccine types, dose and costs for individuals under different vaccination histories

|                   | Vaccinated before     |                  | Not vaccinated before |                  |
|-------------------|-----------------------|------------------|-----------------------|------------------|
|                   | Vaccine type and dose | Vaccination cost | Vaccine type and dose | Vaccination cost |
| Under 6 years old | 2 dose OPV            | 1.40 US\$        | 3 dose IPV            | 4.65 US\$        |
| Above 6 years old | 1 dose IPV            | 1.55 US\$        | 3 dose OPV            | 2.10 US\$        |

Table 2: The 2017 population of the five cities that have the highest refugee population based on age, region, and vaccination history, adopted from [1, 12]

| Cities    | Population of the refugees |                |                       |                | Population of the refugees not vaccinated against polio |                |                       |                |
|-----------|----------------------------|----------------|-----------------------|----------------|---|----------------|-----------------------|----------------|
|           | Refugees live in camps     |                | Refugees out of camps |                | Refugees live in camps                                  |                | Refugees out of camps |                |
|           | 6 <sup>-</sup>             | 6 <sup>+</sup> | 6 <sup>-</sup>        | 6 <sup>+</sup> | 6 <sup>-</sup>  | 6 <sup>+</sup> | 6 <sup>-</sup>        | 6 <sup>+</sup> |
| Istanbul  | 0                          | 0              | 70,396                | 138,955        | 0   | 0              | 31,678                | 62,529         |
| Sanliurfa | 16,266                     | 38,758         | 46,522                | 91,830         | 4,066   | 9,689          | 20,935                | 41,323         |
| Hatay     | 2,851                      | 6,794          | 53,857                | 106,308        | 712   | 1,698          | 24,235                | 47,838         |
| Gaziantep | 5,878                      | 14,008         | 42,738                | 84,360         | 1,469   | 3,502          | 19,232                | 37,962         |
| Adana     | 86                         | 205            | 23,181                | 45,758         | 21  | 51             | 10,431                | 20,591         |

\*6<sup>-</sup> refers to the individuals under 6 years old, where 6<sup>+</sup> shows the individuals between 6 and 12 years old

The problem of deciding optimal number of vaccines for each age and location considering the budget limit is modeled by a mixed integer linear programming model. The sets, parameters, variables of the model are listed below.

Sets and indices

- A Set of age groups,  $A=\{0-59 \text{ month}, 59^+ \text{ month}\}$   
C Set of cities,  $C=\{\text{Istanbul, Sanliurfa, Hatay, Gaziantep, Adana}\}$   
H Vaccination history,  $VH=\{\text{Vaccinated local population, Non-vaccinated population inside camps, Non-vaccinated population outside camps}\}$

Parameters

- $pop_{cah}$  : Population of city  $c$ , age group  $a$  with vaccination history  $h$   
 $m_{ah}$  : Vaccination cost of individual at age  $a$  with vaccination history  $h$   
 $HRB$  : Minimum ratio of the individuals that needs to be vaccinated at high risk age group (age 6<sup>-</sup>)  
 $LRB$  : Minimum ratio of the individuals that needs to be vaccinated at low risk age group (age 6<sup>+</sup>)  
 $CL_c$  : Minimum number of individuals that needs to be vaccinated in each location  
 $R$  : Unit overstock cost,  $W$  : Unit shortage cost,  $B$  : Vaccination budget

Variables

- $V_{cah}$  : Number of individuals vaccinated in location  $c$ , age group  $a$  with vaccination history  $h$   
 $C_o$  : Total overstock cost  $C_u$  : Total shortage cost  $NV$  : Total number of individuals vaccinated

The mixed integer programming model is presented in Equations (1-9). Objective function in Equation (1) maximizes the number of individuals vaccinated against polio. Constraint (2) ensures that the vaccination budget cannot be exceeded. Equation (3) shows the calculation of overstocking cost, where Equation (4) presents the calculation of shortage cost. Constraint (5) states that the number of vaccinated individuals in location  $c$ , age group  $a$ , and that have vaccination history  $h$  does not exceed the population in that group. Vaccination history shows whether the individual is vaccinated or not vaccinated against polio. We classify this indicator variable into three to represent the individuals who are vaccinated, individuals who are not vaccinated and live inside camps, and individuals who are not vaccinated and live outside of camps. Individuals that have missing doses of polio vaccine are considered as if they are not vaccinated. With regards to children's vaccination history, the vaccine dose, type, and thus the vaccination costs differ. Constraint (6) ensures that minimum ratio of vaccinated individuals in location  $c$ , at high risk age group, and vaccination history  $h$  must be greater than  $HRB$ . Constraint (7) ensures that minimum ratio of vaccinated individuals in location  $c$ , at low risk age group, and vaccine history  $h$  must be greater than  $LRB$ . Constraints (6) and (7) are included to prioritize the high risk age group against others. Constraint (8) states a lower bound for each location  $c$  to determine the number of population members to be vaccinated in location  $c$ . Constraint (9) ensures that the number of vaccinated individuals must be a positive integer number.

$$\max NV = \sum_{c \in C} \sum_{a \in A} \sum_{h \in H} V_{cah} \quad (1)$$

s.t.

$$\sum_{c \in C} \sum_{a \in A} \sum_{h \in H} V_{cah} \cdot m_{ah} + C_o + C_u \leq B \quad (2)$$

$$C_o = R \cdot \left[ \sum_{c \in C} CL_c - \sum_{c \in C} \sum_{a \in A} \sum_{h \in H} V_{cah} \right] \quad (3)$$

$$C_u = W \cdot \left[ \sum_{c \in C} \sum_{a \in A} \sum_{h \in H} pop_{cah} - \sum_{c \in C} \sum_{a \in A} \sum_{h \in H} V_{cah} \right] \quad (4)$$

$$V_{cah} \leq pop_{cah} \quad \forall c \in C, a \in A, h \in H \quad (5)$$

$$V_{cah} \geq pop_{cah} \cdot HRB \quad \forall c \in C, a = \{0-59 \text{ month}\}, h \in H \quad (6)$$

$$V_{cah} \geq pop_{cah} \cdot LRB \quad \forall c \in C, a = \{59^+ \text{ month}\}, h \in H \quad (7)$$

$$\sum_{a \in A} \sum_{h \in H} V_{cah} \leq CL_c \quad \forall c \in C \quad (8)$$

$$V_{cah} \in \mathbb{Z}^+ \quad \forall c \in C, a \in A, h \in H \quad (9)$$

### 3. Numerical study

In this part of the study, we determine the optimal number of population that should be vaccinated against polio, and compare vaccination strategies in terms of age and regional priority policies. We perform cost effectiveness comparisons for each strategy and provide a decision support system that could help health care decision makers. Cost effectiveness of vaccination of the total population of children younger than 6 years old, and vaccination of only refugees are compared in the first part of the numerical study. Different lower bounds on the minimum number of vaccines to be administered are compared to perform a trade-off analysis between cost and number of vaccinated individuals. Table 3 presents the optimal number of vaccines and its cost according to varying bounds on the number of individuals to be vaccinated in high and low risk age groups. The first row shows a baseline for the comparison of vaccination costs and the vaccine quantities. Even if the local population is vaccinated against polio at a ratio of 96% [3], the refugees with missing doses of polio vaccine or the refugees that have not been vaccinated at all present health risks for the whole population. Therefore, the decision makers should consider trade-offs between vaccination of the whole population or developing vaccination strategies only for refugees. If the whole population is vaccinated, there is a need of 3,851,749 polio vaccines, which cost 5,127,238 US\$. The total number of vaccines decreases to 337,980 with a cost of 845,238 US\$, if only refugee children are vaccinated. Considering the occurrence rates of polio in Turkey and Syria in 2015 (three cases total), health care decision makers should decide the vaccination rates of the whole population and the risk groups for various ages.

Table 3: Comparison of optimal number of vaccines and cost for different vaccination ratios

| Scenarios          | Only Refugees    |           | Whole Population |           |
|--------------------|------------------|-----------|------------------|-----------|
|                    | Vaccine quantity | Cost (\$) | Vaccine quantity | Cost (\$) |
| HRB 100%, LRB 100% | 337,980          | 845,238   | 3,851,749        | 5,127,238 |
| HRB 95%, LRB 80%   | 287,312          | 743,892   | 3,461,054        | 4,592,674 |
| HRB 70%, LRB 80%   | 270,427          | 727,020   | 3,455,513        | 4,570,776 |
| HRB 90%, LRB 80%   | 281,671          | 721,328   | 3,334,506        | 4,429,052 |
| HRB 80%, LRB 80%   | 270,392          | 676,212   | 3,081,412        | 4,101,818 |
| HRB 80%, LRB 70%   | 247,873          | 636,804   | 2,949,331        | 3,916,327 |

HRB: Minimum ratio of the individuals to be vaccinated in high risk age group (age 6); LRB: Minimum ratio of the individuals to be vaccinated in low risk age group (age 6<sup>+</sup>)

We use the MIP model to compare the distribution strategies considering the groups changing by their a) region (city) only, and b) age only strategies. In the region only strategy, maximum number of the vaccinated individuals is the same and no priority for the age group is applied within a region. In this strategy, we compare the cost effectiveness of different amount of maximum vaccine quantities that are received by each location to vaccinate only refugees or the whole population. While considering the vaccination of the whole population, the maximum numbers of available vaccines for each city are limited by 800K; 700K; 600K; 500K; 400K; 300K and 200K, respectively. Figure 1 shows the total number of individuals vaccinated and the corresponding costs when the region only vaccination strategy is applied to the whole population. In this strategy, all cities have the same amount of maximum available vaccine quantities, and none of the locations has privilege over others. However, since the amounts available for each location are not in levels sufficient to the population size, some cities have vaccine shortages while others have excess inventory. Thus, the cost doesn't increase linearly as the maximum amount of vaccines available for each city increases. Figure 2 shows the total number of individuals vaccinated and the corresponding costs when city only vaccination strategy is applied to refugees. In Figure 2, the maximum numbers of available vaccines are 100K; 90K; 80K; 70K; 60K; 50K; 40K; 30K; 20K and 10K, respectively.

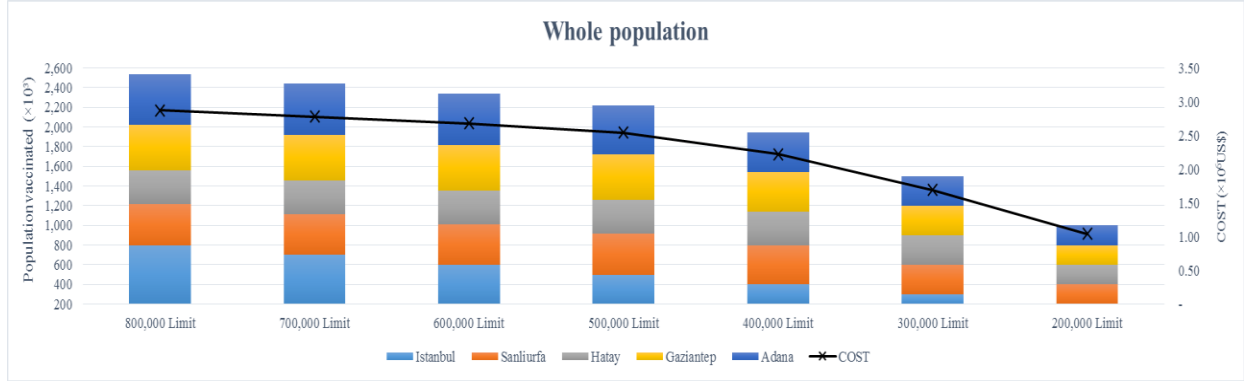


Figure 1: Cost of region only strategy applied to the whole population

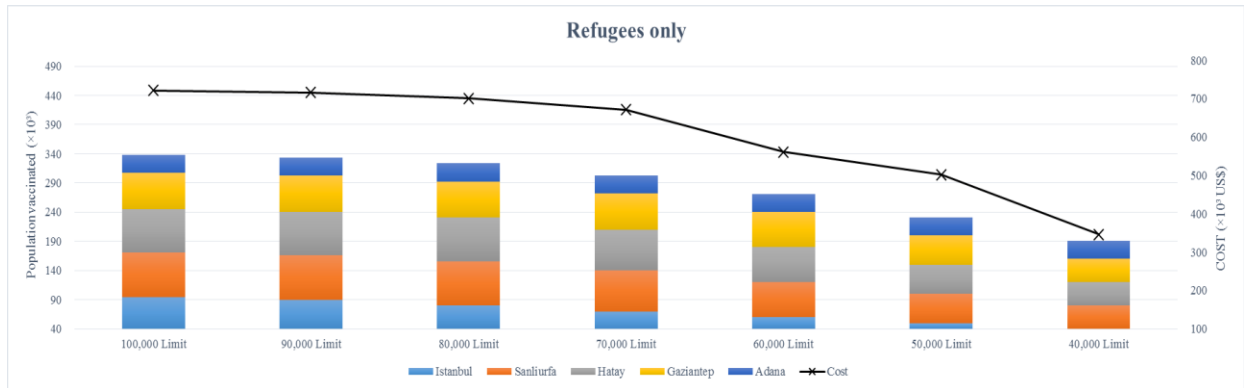


Figure 2: Cost of region only strategy applied to the refugees

In the last part of the numerical study, we compare the cost effectiveness of age-based strategy and mix-strategy in which the maximum number of vaccines available for each city is distributed according to the population and the age-based risk groups. As a base line, no age or region based constraints are included in the model; and the problem is solved considering various available vaccine quantities with the objective of vaccination cost minimization. Then, age based constraints are added into the baseline model. In the age-based strategy, the minimum ratio of the individuals vaccinated in the high risk age group is bounded by 80%. In the mix-strategy, in addition to the age based constraints, the population of the region is also considered. In this strategy, age constraints are included to guarantee that high risk age group is prioritized over others and, the minimum ratio of the individuals vaccinated in the high risk age group is also limited to 80% similar to the age-based strategy. Figure 3 presents the costs of each strategy.

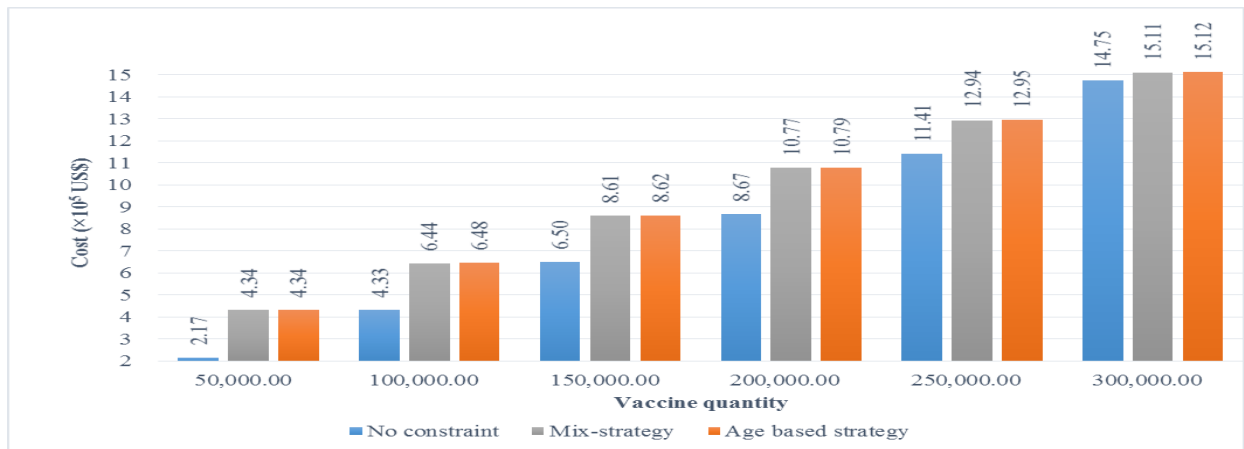


Figure 3: Comparison of aged-based and mix-strategy versus baseline

As seen in Figure 3, the minimum cost is achieved when there are no constraints. However, the baseline case does not prioritize the youngest population to be highly protected. In case of the mix-strategy, not only the age but also the population of each location is considered for distribution of the vaccine quantities. Because the population count is considered, the shortages and inventory levels are lower in comparison to the age-based strategy. Out of the three strategies, age-based strategy costs the highest due to the highest amount of shortages and excess inventory.

#### 4. Conclusion

Vaccination against polio is an effective strategy to prevent from outbreaks [4]. Thus, we consider the problem of polio vaccine quantity determination for each location and age group considering the vaccine history of the individuals. The goal of the developed model is to decide the optimal number of individuals in each location and age group to be vaccinated against polio in an effort to achieve a high level protection. Different vaccination strategies based on age, region, and the age-population (mix-strategy) are compared in cost effectiveness. These strategies are also compared for scenarios under the refugee only and the whole population vaccination policies. The mix-strategy, where the vaccines are distributed according to both the refugee population and the age-based constraints, satisfies the minimum cost strategy since the vaccine inventory costs and relevant shortages are relatively small. In the proposed model, the comparison of different vaccination strategies are only on the cost basis; however, risk analysis with respect to possible spread scenarios of polio should be integrated to the model. Furthermore, integrating the time horizon concept in the MIP model to eradicate the polio virus is another potential future study.

#### References

1. AFAD, 2017, "Field Survey on Demographic View, Living Conditions and Future Expectations of Syrians in Turkey," Republic of Turkey Prime Ministry Disaster and Emergency Management Authority, Available: [https://www.afad.gov.tr/upload/Node/25335/xfiles/17b-Field\\_Survey\\_on\\_Demographic\\_View\\_Living\\_Conditions\\_and\\_Future\\_Expectations\\_of\\_Syrians\\_in\\_Turkey\\_2017\\_English\\_1.pdf](https://www.afad.gov.tr/upload/Node/25335/xfiles/17b-Field_Survey_on_Demographic_View_Living_Conditions_and_Future_Expectations_of_Syrians_in_Turkey_2017_English_1.pdf) [Accessed 2018-11-30].
2. WHO, 2002, "Fifteenth Meeting of the European Regional Commission for the Certification of Poliomyelitis Eradication," Available: [http://www.euro.who.int/\\_data/assets/pdf\\_file/0003/79374/E88105.pdf](http://www.euro.who.int/_data/assets/pdf_file/0003/79374/E88105.pdf) [Accessed 2018-11-25].
3. Jorba, J., Diop, O. M., Iber, J., Sutter, R. W., Wassilak, S. G., Burns, C. C., 2016, "Update on Vaccine-derived Polioviruses—Worldwide, January 2015–May 2016," *MMWR. Morbidity and Mortality Weekly Report*, 65, 763-769.
4. Bandyopadhyay, A. S., Garon, J., Seib, K., and Orenstein, W. A., 2015, "Polio Vaccination: Past, Present and Future," *Future Microbiology*, 10(5), 791-808.
5. Jacobson, S. H., Sewell, E. C., Deuson, R., and Weniger, B. G., 1999, "An Integer Programming Model for Vaccine Procurement and Delivery for Childhood Immunization: A Pilot Study," *Health Care Management Science*, 2(1), 1-9.
6. Smalley, H.K., Keskinocak, P., Swann, J., and Hinman, A., 2015, "Optimized Oral Cholera Vaccine Distribution Strategies to Minimize Disease Incidence: A Mixed Integer Programming Model and Analysis of A Bangladesh Scenario," *Vaccine*, 33(46), 6218-6223.
7. Duijzer, L. E., van Jaarsveld, W., and Dekker, R., 2018, "Literature Review: The Vaccine Supply Chain," *European Journal of Operational Research*, 268(1), 174-192.
8. Assi, T.-M., Brown, S.T., Kone, S., Norman, B. A., Djibo, A., Connor, D.L., Wateska, A. R., Rajgopal, J., Slayton, R.B., and Lee, B.Y., 2013, "Removing the Regional Level from the Niger Vaccine Supply Chain," *Vaccine*, 31(26), 2828-2834.
9. Brown, S. T., Schreiber, B., Cakouros, B.E., Wateska, A.R., Dicko, H.M., Connor, D.L., Jaillard, P., Mvundura, M., Norman, B.A., and Levin, C., 2014, "The Benefits of Redesigning Benin's Vaccine Supply Chain," *Vaccine*, 32(32), 4097-4103.
10. Lee, B. Y., Connor, D. L., Wateska, A. R., Norman, B. A., Rajgopal, J., Cakouros, B. E., Chen, S.-I., Claypool, E. G., Haidari, L. A., and Karir, V., 2015, "Landscaping the Structures of GAVI Country Vaccine Supply Chains and Testing the Effects of Radical Redesign," *Vaccine*, 33(36), 4451-4458.
11. Republic of Turkey Ministry of Health, 2008, "Expanded Program on Immunization Program." Available <https://dosyasb.saglik.gov.tr/Eklenti/1117.gbpgenelge2008pdf.pdf?0> (in Turkish) [Accessed 2018-12-05].
12. Turkish Statistical Institute, "Regional Population Statistics," Available: <https://biruni.tuik.gov.tr/bolgeselistatistik/tabloyilSutunGetir.do?durum=yillariGetir&menuNo=251&altMenuGoster=0&tabloNo=158#> (in Turkish) [Accessed 2018-11-15].